U.S.-JAPAN ADVANCES IN DEVELOPMENT OF OPEN-OCEAN RANCHING

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ABSTRACT

Seafood species throughout the world have begun to decline and the notion of sustainable fisheries has begun to grow in importance. Yet, government policies continue to emphasize weaker approaches—prevention, limitation of new technologies, fines—and the conventional—hatcheries to re-populate, land-based aquaculture, and marine cages. The former only exacerbates an already desperate situation, while the latter sometimes adds to coastal pollution. Clearly, there must be a more enlightened and effective system for cost-competitively producing more seafood without deleteriously affecting the marine environment. An international team led by Japan and the United States has been functioning to accomplish this task.

INTRODUCTION

Nearly half of all fish caught come from less than 0.1% of the ocean surface, where a favorable set of wind, current, and nutrient conditions allow for natural upwelling, which, unfortunately, can be uncertain as experienced off the coast of Peru. However, recent research has developed a new concept for open-ocean ranching based on artificial upwelling. Ocean ranches will someday feature the enhancement of open-sea biological productivity through induced flow of deep-ocean nutrients by means of ocean thermal energy conversion (OTEC) and other upwelling mechanisms. Seafood products will be derived by the management of integrated "floating grazing platforms," which might also catalyze atmospheric carbon dioxide sequestration. (There have been reports that nearly all carbon dioxide emissions can be absorbed by a biomass plantation or marine biotechnology reactor. While the concept remains somewhat untested, the prospects are that, at worst, the carbon dioxide emitted into the atmosphere will be at least a factor of ten less than if fossil fuels were used to produce a like amount of electricity. It might someday become fashionable and sensible to design a total package where surface cooling can prevent hurricane formation and biological carbon dioxide sequestration might remediate global climate warming. No one has yet begun addressing these combined challenges.)

Commercialization of the concept will be enhanced by the fullest possible integration of value-generating activities. While conservative ecological parameters and assumptions result in only about $3.3 million in aquatic food products produced annually from a hypothetical 10 MW OTEC plant, more optimistic calculations for a 1,000 MW facility suggest a figure exceeding $1 billion a year from seafood alone. The urgency of the food problem and the lack of nullifying obstacles indicate the need for further evaluation of this concept. There is great development potential but much to be learned.

World capture fishery landings increased through the 1980s, but have since leveled near 90 million metric tons per year, the long-forecast maximum sustainable yield. Catches have thus failed to increase with demand and have declined on a per capita basis. As would be expected, seafood prices have dramatically increased relative to beef, chicken, and other high-protein foods. Worse yet, approximately two-thirds of the 200 important commercially fished stocks are fully or over-exploited. Many marine fisheries have been depleted, some to the point of economic extinction, while others have been closed in hope of recovery.

Aquaculture now contributes more than 20% to global aquatic food production, with more than two-thirds of the harvest derived from fresh waters in Asia. Total annual production of fish and shellfish is slightly in excess of 100 million tons (FAO, 1998). The expansion of aquaculture, however, remains dependent on feeds containing fish meal protein derived from fully exploited capture fisheries. The substantial increases of recent decades in aquaculture production have not been sufficient to outpace population growth and demand, nor to prevent declining total (capture plus culture) per capita production of aquatic food products and consequent price increases.

Advancements similar to the Green Revolution and the ongoing expansion of aquaculture will be required if the food problem is to be solved. However, land use for terrestrial food production competes with maintenance of forests and natural ecosystems, with potential consequences to global climate change. A "Blue Revolution" can provide increased protein production while improving the environment. While the Green Revolution was a Nobel Prize-winning concept that enabled many developing countries to produce more food to feed their populations, a Blue Revolution has the potential for greatness far beyond mere agricultural commodities—food, energy, materials, habitats, environmental enhancement, and other outcomes.

Even with a presumption of future consensus on global food policy, there remains a limit to the potential for production of food protein on earth. Maximizing the conventional production rate would require rapid and efficient recycling of limiting nutrient elements. This condition cannot be attained because natural systems, both forests and the open sea, sequester organic matter in detrital pools (forest litter and soil, deep-sea detritus) having long residence times and absolute regeneration rates insufficient for significant expansion of production. Accessing the nutrients of the deep sea, on the other hand, is a potential means of expanding production of food protein with neutral or favorable impact on oxygen and carbon cycles, and a longer term of sustainability exceeding millennia, whereas on land, trees die after decades or centuries, returning the carbon dioxide to the atmosphere.

In next-generation ocean ranches, biological productivity of open-sea areas will be enhanced through artificial upwelling of nutrient-rich subsurface sea water into the photic zone. Early experiments could use surge pumps or other marine technologies to move 500 m deep fluid into the photic zone. Seafood and other products will be derived by integrated management of the nutrient-enriched ocean. At the final stage, OTEC can bring into productive use the cold deep water underlying the unproductive but vast subtropical seas (Figure 1). Ancillary benefits include potentially enhanced carbon dioxide sequestration (Dunn et al., 1997), net oxygen production in the photic zone, and, as noted earlier, cooling of the ocean surface over significant geographical areas that could mollify storm formation (NSF/JSTA, 1990; Takahashi, 1996). The required information base required for critical evaluation of the complete concept does not now exist. Intermediate stages will yield useful increments of food from untapped nutrient resources and generate the information base.

Developing technologies provide a potential pathway to this vision, but critical questions stand at the gateway and undoubtedly along the path. Reviewed will be some of the component technologies that will need to be integrated, and a preliminary estimate of production potential will be made.

MARINE SYSTEMS

In the early stage, ocean ranching via open-sea grazing platforms will probably require infrastructure and culture support facilities similar to those of open-water aquaculture operations. Intensive photosynthetic production of biomass for larval rearing or other purposes may involve confinement of upwelled water. Cage culture facilities may be required if juvenile fish are grown to their optimal release size in cages, or when product fish are caged pending harvest. Floating platform technology for commercial aquaculture is reasonably well-developed; open-seaworthiness is a continuing development goal. Cages can be positioned tens of meters below the wave-influenced surface layer, with the ability for variation of depth. Most systems to date have been moored to the sea floor, but there are mooring-free designs in development.

Culture facilities have not yet been integrated with the generally larger-scale hardware developments aimed at other purposes. Very large floating structure (VLFS) technology may readily accommodate the requirements of the aquaculture component (NSF/JSTA, 1996). There are no large-scale OTEC deployments in the open sea, but designs exist. The developing technologies of floating breakwaters will also be useful, particularly the concept of large circular breakwater structures with central "lagoons" suggestive of oceanic atolls.

Floating platforms of any type and size will attract fishes; a characteristic community will develop if a facility remains in place for a sufficient time. This phenomenon has been used to the advantage of commercial and recreational capture fisheries by the deployment of anchored fish aggregation devices. The impact and potential utility of this aggregation effect on the neighborhoods of platforms will need to be assessed.

Artificial upwelling is a key technological concept to this vision because only by augmentation of the inorganic nutrient supply to the photic zone can there be enhancement of marine photosynthesis-based food chains leading to harvestable protein. Oceanographers use the term "new" production for the portion of photosynthetic production derived from nutrients that have moved (however slowly) into the photic zone from below the base of the mixed layer, as distinct from production supported by nutrient recycling within the mixed layer. Thus, the upwelling mariculture concept aims to accelerate new production in the sea. Recent open-ocean iron-enrichment of the sea surface in natural upwelling zones stimulated productivity, suggesting that further supplementation of artificially upwelled nutrients might also intensify photic zone enrichment. Laboratory experiments have supported this supposition.

Artificial upwelling can be produced by a variety of means. Existing land-based research facilities (Toyama Bay and Kochi in Japan and at the Natural Energy Laboratory of Hawaii Authority) produce artificial upwelling with conventional pumps. In the first sizable test of ocean fertilization, the HOYO experiments at Toyama Bay in 1989 and 1990 involved pumping 50,000 tons of deep ocean water from the 200 m depth to the surface, mixing it with three parts of surface water, and spraying it on the bay. A wave-driven artificial upwelling device has been developed at the University of Hawaii, which will permit small-scale examination of plume behavior and management strategies. A wide range of experiments in Japan will be described later.

Ultimately, the “grazing platforms” will be powered by OTEC, which will draw water up from depths near 1,000 m with temperatures below 5° C. Should other sustainable technology options be utilized, such as surge pumps, a depth in the range of 500-600 m will provide nitrate and phosphate at concentrations near 90% those of the deepest ocean depths. These nutrient concentrations are greater than those of the thermocline-depth waters that supply the world’s natural upwelling zones, which in turn account for a major portion of world fishery production.

The practical region of the ocean for OTEC is approximately that of deep waters in the tropics, the actual area being affected by land masses and ocean currents. Both closed-cycle and open-cycle plants have been operated at the Natural Energy Laboratory of Hawaii Authority (NELHA) in Kailua-Kona on the island of Hawaii, as research and demonstration projects by the Pacific International Center for High Technology Research (PICHTR). Although the more distant future for OTEC will likely lead to relatively large floating facilities, a nearer-term application may be in land-based plants of 1-10 MW capacity, designed for small island developing states and funded by international aid agencies. This might be examined as a collaborative means to initiate an upwelling mariculture platform trial.

The artificial upwelling concept has generated considerable research literature, which contains specifics pertinent to initial design considerations, biological experimentation on effects of enrichment of surface waters with nutrients from thermocline depths, and pre- and post-deployment ecological surveys of OTEC test sites. Physical oceanography, including plume characteristics and behavior, has been addressed. Upwelled waters discharged near the surface of the sea tend to sink as they mix with surface water, and can be traced as water masses to their depths of equilibrium density. Such waters can move fairly rapidly away from an anchored source. It is possible, on the other hand, for a mobile facility to track the plume precisely, as was done for the aforementioned iron experiments. Upwelled water can be effectively mixed with surface water to control its mixing behavior.

OPEN-OCEAN RANCHING

Ocean ranching is the second key concept to our vision. Except for the case of salmon, ocean ranching is at present less well-developed technologically and commercially than confined open-ocean aquaculture. Ocean ranching is related to the idea of fisheries stock enhancement, in that advantage is taken of growth in the biomass of released hatchery stock, supported by the natural productivity of the sea. Ocean ranching differs in its inclusion of technological advantage in control or recovery of the stock. In the case of salmon, their anadromous nature causes them to seek to return to the stream system of their origin, though they are typically captured en route. With other species, means for recapture may include natural barriers, of water temperature for example, that keep organisms from dispersing from the stocking point unduly, and technological strategies for concentration and recovery (behavioral training for response to artificial stimuli such as sound). Much of the existing research is from Japan. Upwelled cold water potentiates temperature isolation of the stock; the renewable energy source is available for other recovery and harvest strategies.

Near-shore ocean ranching necessarily involves issues of proprietorship, tenure, and shared use of ocean areas. These issues have not been addressed for the case of mobile platforms in the open sea. But it would be intriguing to leap-frog existing terrestrial farming and ranching systems (which are energy-intensive and add carbon dioxide to the atmosphere) with an OTEC-powered ocean ranch that is driven by natural energy, feeds itself, operates without cages, and can explore using acoustic techniques during the harvest.

Species selection and development for the fisheries products are critical for sufficient productivity as well as for consideration of impact on oceanic ecosystems. Upwelling is expected to produce “natural” changes in the species composition of the fertilized microbial communities.

With artificial upwelling providing nutrients, food-chain efficiency of the product would be greatest for a readily harvested primary producer, such as edible macroalgae. Seaweeds are not, however, a concentrated form of protein, and it is questionable that such a product could be competitive with present culture systems on and near land.

Food-chain efficiency with an animal product will be greatest with a planktivorous herbivore or filter-feeder. Whale sharks, under study at the Sun Yat Sen University aquarium in Taiwan, or presently cultured herbivorous species such as rabbit fish, would be examined for feasible use in these systems. Their advantages include the ability to grow rapidly to desirable market sizes and efficiency for protein production under limited nutrient conditions. Genetic engineering can be considered or transgenic varieties might need to be developed, for, say, creating a red rabbit fish.

The fisheries productivity of the natural upwelling zones is derived from small planktivorous fishes (anchovies and sardines), some of which have been cultured. The depletion and decreasing reliability of the upwelling zones’ capture fisheries, which produce fish meal used by the terrestrial and aquatic animal feed industry, suggests a ready market for filter-feeding fishes as efficient products of upwelling mariculture systems.

Natural trophic position is by no means the sole determinant of a species’ potential for efficient aquaculture production. Numerous species, which in nature are carnivorous or omnivorous, have been developed for practical culture in open-water systems using fish meal- and fish oil-based feeds economically. Such systems, however, consume rather than enhance oceanic productivity of bulk foodstuffs, though they produce economic value. A small-fish production strategy could gain advantage from the facts that larvae and juveniles of most fish species are planktivorous, that some are likely faster-growing and more amenable to culture than the upwelling zone planktivores, and that these species are of high value even at small food portion sizes. Open-water oceanic fishes (mahimahi, tuna) tend to grow rapidly as a natural adaptation against predation in an environment devoid of shelter, but unless feed technology advances rapidly, natural carnivores may be unprofitable to culture.

An OTEC plant of sufficient size to substantially enhance fertility in its vicinity will generate more power than is needed to support the aquaculture activity. Excess power could generate exportable hydrogen fuel, perhaps in combination with a demonstration of new techniques for the sea bed harvesting of methane hydrates. Platforms may well be large enough for profitable harvest of solar energy by photovoltaic cells. Secondary research uses would bring with them funding to defray overhead costs.

The term “integrated farming” has been associated mainly with subsistence agriculture, but has begun to be applied to industrial farming. Integration concepts could be used on upwelling mariculture platforms to minimize organic discharges and grow additional crops by recycling carbon and nutrient elements in dissolved and particulate forms through further biological uses. Excess stock of phytoplankton may be used to culture filter-feeding organisms such as shelled mollusks; fishes other than the primary crop may be produced on excess zooplankton and non-living particulates, and possibly used as additional feedstock for the primary crop animal; other microbes may process dissolved organic matter, for example producing hydrogen as done by "purple non-sulfur" bacteria and, as marine biomass, can convert sunlight from two to five times more efficiently than any land crop. Macroalgae, for example, can be harvested and converted on the platform into biofuels and “green” chemicals such as plastics and pigments. A primary crop of fish produced on a grazing platform could have its feed supply supplemented with the by-catch of nearby capture fisheries, thus addressing a global fisheries problem.

DEVELOPMENTAL PROGRESS

While the Natural Energy Laboratory of Hawaii Authority, located next to the Keahole Airport on the Big Island of Hawaii, has experienced the most advancements in providing the marine technologies for ultimate transfer into the open ocean, admirable progress is also being shown at the prefectural laboratories in Kochi and Toyama in Japan. A new facility is undergoing shake-down tests in Okinawa, and the Japan Ministry of Agriculture and Fisheries has announced that up to three new deep-ocean pipe systems will be supported over the next few years. Thus, within the decade, Japan, by itself, will have more than half a dozen NELHA-type facilities.

Over the past two decades, a number of presentations were given at UJNR, reporting on NELHA. To summarize:

- NELHA began in 1974, was the home base for Mini-OTEC, which first produced net positive electricity, and later hosted all the important OTEC experiments of the U.S. Department of Energy through the Pacific International Center for High Technology Research.

- The land on which NELHA is situated consists of 870 acres on the west side of the Big Island of Hawaii at Keahole Point, adjacent to the Keahole International Airport.

- Cold, deep, sea water is delivered at 6° C, while surface temperatures range from 24.5° to 27.5° C.

- Annual insolation is the highest of any location in the coastal United States.

- There are more than 25 tenants, producing products such as marine biotechnology biopigments, abalone, pearls, thorium (for tracer studies), oysters, clams, cold-water fruits and vegetables, microalgae, shrimp broodstock, lobsters, ornamental reef and edible fish like threadfin and hirame, myco-medicinal mushrooms, sea vegetables, and fresh water,

- Also located there are global climate change research efforts, the University of Hawaii Sea Grant Extension Service, West Hawaii Explorations Academy (for pre-college students), and the National Defense Center of Excellence for Research in Ocean Sciences, the latter which has provided nearly $40 million in research grants to the private sector for ocean research and development.

- NELHA is a "landlord" supporting more than $30 million in ocean enterprises at the site.

In Japan, the initial focus of artificially upwelled waters was on aquaculture. Experiments were conducted in various laboratories and expanded to Kochi and Toyama, with funding from the Japan Marine Science and Technology Center and prefectural goverments. More recently, diversification into seasonings, drinks, drugs, and cosmetics are in a variety of production and marketing stages.

Among the key recent achievements and plans for Japan include:

- The New Energy and Industrial Technology Development Organization (NEDO) has initiated a five-year research and development program for utilization of deep sea water resources, funded by the Ministry of International Trade and Industry. This includes:

  (a) For low-temperature applications, 1 million tons per day of cooling water for a 300 MW existing electrical power plant, with four tasks: pumping deep sea water at a high rate; using energy and other resources; minimizing environmental effects; and total model feasibility design for several typical locations.

  (b) For open ocean applications, a float named *Umiyakara 1* was moored in 1997 to a depth of 1,760 m at a site 30 km south of the main island of Okinawa, where two pipelines of 50 mm inside diameter were installed to pump up deep sea water from depths of 800 and 2,000 m for fertilization experiments. A second float, *Umiyakara 2000*, was moored to a depth of 2,100 m in 1999. Beginning this fiscal year, a new five-year program was launched by Marino Forum 21, with financial support from the Fisheries Agency of Japan.

- Mega-Float, a very large floating structure currently undergoing tests in Yokosuka Bay, has been proposed by Tetra Corporation to be relocated to a reef environment in southern Japan for multiple applications.

- The Nippon Kokan Project has been studying the feasibility of utilizing a plant-ship similar to Mega-Float to be used as an ocean ranching base featuring cages.

- Marino Forum has created Ukigysho, an artificial reef to act as an oasis in the ocean. The reef, at a depth of 80 m off Nagasaki, is a twin-peak sea mount of 15 m height utilizing 5,000 pieces of 1.6 m cubed concrete blocks made of fly ash supplied from a neighborhood coal electric power plant. It will enhancevertical turbulent mixing of bottom sea water to bring nutrients to the surface.

- The Japan Association of DOWA (JADOWA) has sponsored a series of meetings and seminars on this subject and is partnering with the Pacific International Center for High Technology Research to develop open-ocean ranches.

FORMATION OF RESOURCES OF THE OCEAN, INTERNATIONAL, 21st CENTURY (ROI21)

To integrate these scattered experiments into a cohesive, long-term, ocean ranching program, a team of scientists and engineers from Japan and the United States has met over the past two years to create Resources of the Ocean, International, for the 21st Century, or ROI21. A follow-up meeting of this group will occur in 2000 to fully establish the partnership.

In parallel, the International Ocean Alliance Summit, held at the East-West Center in Honolulu in December 1998, assessed the potential for the construction and operation of a floating platform in the Hawaiian Exclusive Economic Zone; identified and ranked possible platform applications (e.g., energy generation, research base, industrial use, airports, public works, fisheries, recreation/entertainment) based on relevance to testing and operation in Hawaii; pointed out key technical issues requiring development; reviewed financing options and opportunities for international business partnerships; clarified regulatory and other permitting issues; formulated a development plan for submittal to the Hawaii Legislature and other potential funding sources, emphasizing commercial applications rather than pure academic research purposes; and established linkages between private and public entities.

An important, but longer-term application, included ocean ranching. Thus, ROI21 will coordinate with the International Ocean Alliance partnership in the development of a 10-year plan for transferring much of the offshore Japanese experimental data and NELHA information for an open-ocean ranch system.

CONCLUSIONS

World fisheries prospects are precarious. Seafood prices are escalating. Nutritional and demographic patterns all point to increasing demands that will only be met with a virtual Blue Revolution in marine biological systems development. The concept of artificially upwelled ocean ranches holds promise if it is possible to utilize very large floating structures to provide natural energy to pump deep ocean water through the OTEC process, where the spent high nutrient effluent is maintained in the photic zone to support biological growth, and nutrient or temperature barriers can effectively contain the seafood species. Harvesting will be accomplished through acoustic techniques, and environmental enhancement could well become an important added value, certainly through transfer of coastal mariculture enterprises away from populated areas, but also possibly through atmospheric reduction of carbon dioxide and ocean cooling, contributing to remediation of global climate warming and assessing the potential of hurricane prevention.

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